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A NOMOGRAPHIC METHOD FOR BOTH PREDICTION AND
OBSERVATION CORRELATION OF IONOSPHERE CHARACTERISTICS

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The variations of ionosphere characteristics -- critical frequency, maximum usable frequency, and virtual height, -- are functions of solar activity, season, local time of day, latitude and longitude. (cf IRPL-R4, "Methods Used by IRPL for the Prediction of Ionosphere Characteristics and Maximum Usable Frequencies".)

As a measure of solar activity, sunspot numbers may be used. The variation of the twelve-month running average of monthly average ordinary-wave critical frequencies at a given location and a given time of day is approximately a linear function of the twelve-month running average of monthly average sunspot numbers.

The sunspot numbers used herein are the Zurich relative sunspot numbers, which are disseminated by the Department of Terrestrial Magnetism, Carnegie Institution of Washington and published regularly in "Terrestrial Magnetism and Atmospheric Electricity". These sunspot numbers were begun by Wolf, and continued by Wolfer and Brunner, at Zurich. The numbers are obtained from solar observations of individual spots and spot groups made at various observatories, reduced to the same basis by using the following formula:

$$\text{Relative sunspot number} = C(10G + N),$$

where G is the observed number of spot groups, N the total observed number of spots, and C a number, depending upon the type of telescope used, seeing conditions, and other factors affecting the observation, which brings the observations into best general consistence with the original Wolf numbers. The figure 10 was arbitrarily chosen by Wolf in order to give greater weight to the large active solar areas constituting spot groups than to small spots of short duration, so that the relative sunspot numbers might serve as a better measure of general solar activity.

The twelve month running average of monthly average ordinary-wave critical frequencies at any location may be expressed as

$$f_o^{12 \text{ mo.}} = f_1(t) + S [f_1^0(t)] \text{ --- (1)}$$

where t is the local time of day, $f_1(t)$ the diurnal variation of critical frequency for a sunspot number zero, S , the twelve-month running average of monthly average sunspot numbers, and $f_1^0(t)$ the diurnal variation in slope
(over)

of the linear trend curve correlating the twelve-month running averages of monthly average critical frequencies and sunspot numbers. $f_1(t)$ always turns out to be a positive quantity. In the case of F2-layer critical frequencies, neither $f_1(t)$ nor $f_1(t)$ are simply expressed functions.

For any month, the variation of ordinary-wave critical frequencies may be determined by multiplying the value $12 \text{ mo. } \overline{f^0}$ by a monthly index, X , for each hour of local time. (X , as used in the present report, signifies the product of "seasonal index" and "monthly index" as used in the previously cited report, IRPL-R4.)

The variation of X with twelve-month running averages of monthly average sunspot numbers seems also to be approximately linear, although this variation is usually small and, for most locations, poorly determined because of an insufficient accumulation of data.

Thus,

$$f^0 \approx X \cdot 12 \text{ mo. } \overline{f^0}, \text{ --- (2)}$$

$$\text{where } X = f_2(t) + S \left[f_2'(t) \right] \text{ --- (3)}$$

$f_2'(t)$ is sometimes positive, sometimes negative.

The maximum usable frequency for vertical incidence (zero transmission distance) is the extraordinary-wave critical frequency, f^x , which is related to f^0 and the gyrofrequency for the location, f_H , by the expression

$$f^0 = f^x \sqrt{1 \pm \frac{f_H}{f^x}} \text{ --- (4)}$$

For fairly long transmission distances, (approximately 1500 km - 4000 km), the maximum usable frequency may be obtained, with a fair degree of precision, by multiplying the value f^0 by a "maximum usable frequency factor", M , pertinent to the distance under consideration.

For the best determination of F2-layer maximum usable frequency, M for a standard distance of 4000 km, (the maximum distance for single-hop transmission) is used, maximum usable frequencies for other distances being determined from the 4000-km maximum usable frequency and the zero-distance maximum usable frequency by means of the method given in the reports of the IRPL-D series (Army TB11-499, Navy DNC-13-1 series), "Basic Radio Propagation Predictions Three Months in Advance".

This 4000-km maximum usable frequency (4000-MUF) is thus given by

$$4000\text{-MUF} \approx [M_{4000}] f^0 \text{ --- (5)}$$

The factor M_{4000} (the maximum usable frequency factor for 4000-km) also varies with solar activity, season, and local time of day in a manner similar to the variations of f^0 and X where

$$[M4000] = f_3(t) + 5 \left[f_3^0(t) \right], \text{ --- (6)}$$

all values of $f_3^0(t)$ being negative, and small relatively to $f_1^0(t)$.

Equations (1), (3), (4), and (6) are all essentially of the same type, containing the sum of one function, each, of two variables, and the product of a second function of one of these variables with a function of a third variable, and may all be represented nomographically in a similar manner. If X and $M4000$ are considered invariable with respect to solar activity -- a sufficiently good assumption for many practical purposes, since such variation is usually slight, poorly determined, or unknown, equations (2) and (5) may also be represented in this fashion.

In order to illustrate the types and uses of such nomograms, a series prepared for the location Washington, D.C., based upon F2-layer observations extending from May, 1933, until the present time, is given herewith.

Fig. 1 presents rather accurately the values of $12 \text{ mo. } \overline{f^0}$, as expressed in Eq. 1. Less accuracy over the range of sunspot numbers is given by the nomograms of Figs. 2, 3 and 4 which give values of f^0 , as in Eq. 2, for the months of June, September and December, respectively, where the value of X is assumed constant, -- the average of all observed values, -- although the precision is fairly good for a sunspot number in the neighborhood of 60. The overall accuracy, however, is amply sufficient for most practical purposes of prediction. The need for greater precision of prediction is ordinarily associated with use over a limited range of sunspot number, and, if pertinent values of X are taken for this limited range, a rather high degree of precision is possible, inasmuch as the solar-activity variation in X is usually slight.

A measure of the variation of the monthly index, X , over the range of sunspot numbers is given by the nomograms of Figs. 5, 6 and 7, which present the variation expressed in Eq. 3 for the same months. It is to be noted that the monthly index (X) scale of Fig. 7 (December) is reversed with respect to the scales of Figs. 5 and 6. With this reversal a marked similarity is apparent between the time scale for this month and that for June, shown on Fig. 5. A more accurate, but also more laborious, determination of f^0 than that given by Figs. 2, 3 and 4, is afforded by multiplying values of $12 \text{ mo. } \overline{f^0}$ given by Fig. 1 with values of X determined from Figs. 5, 6 or 7.

f^X may be obtained from f^0 and f_H by means of the nomogram, Fig. 8, by entering the value of f_H appropriate to the location. (cf IRPL Radio Propagation Handbook, Part 1, Fig. 9). As may be noted, this nomogram is applicable to all locations, and not restricted to use for Washington, D.C.

The 4000-km maximum usable frequency for the same months, assuming no variation of X or $M4000$ with sunspot number, is given by the nomograms of Figs. 9, 10 and 11, these corresponding to Eq. 5 combined with Eq. 2.

The nomograms of Figs. 12, 13 and 14 indicate the variation of M^{4000} expressed by Eq. 6, the inversion of one vertical scale being necessary because of the negative values of $f_3(t)$.

The most precise determination possible for the 4000-km muf is by means of the combined use of nomogram Fig. 1, with X determined from Figs. 5, 6 or 7, and M^{4000} determined from 12, 13 or 14, or by limiting the range of sunspot numbers in construction of the nomogram, as indicated previously for determination of f^0 .

Although for clarity of presentation, a separate nomogram is here given for each of the three months under consideration, greater condensation of material as well as greater facility in seasonal interpolation may be effected by combining the central scales of local time of day, for all months, on one nomogram, the central area thus representing a curve-mesh with values of time of day and season of year as two sets of parameters.

Alternatively, such nomograms may be constructed for some particular month, but with the central area representing a curve-mesh with values of time of day and latitude as parameters (longitude being taken as constant or zoned), thus giving world coverage of the predictions after the manner of the prediction charts regularly issued in the IRPL-D series, previously cited.

The chief advantage of nomographic methods of presentation is generally that of space economy in the correlation of several variables. This particular type of nomogram, in addition, possesses three other great practical advantages:

1. The variation of sunspot number appears as an independent scale.

(a) Since prediction of usable frequencies depends primarily upon the prediction of sunspot numbers, this enables rapid revisions of frequency predictions with revisions of sunspot predictions. This is especially valuable at the present time, and will remain so until the next sunspot maximum has been passed, for long-time predictions of sunspot number during times of increasing solar activity are notoriously unreliable.

(b) Nomograms of this type, although needing revision for increased precision resulting from added observations at new locations, will need rather little revision for regions in the proximity of old ionosphere stations, and thus will be relatively good for all time. This is of great advantage where timeliness in distribution of predictions is difficult. Nomograms of this type may be issued at any time in advance of their period of usefulness, with tentative predictions of sunspot numbers; revised predictions of sunspot number may be easily telegraphed to the recipients.

(c) The entire range of probable variation in useful frequency may be readily estimated. This is of particular value in the consideration of frequency allocation or equipment design or purchase, where effective use is desired over a considerable period of time. Nomograms

of the types shown in Figs. 2, 3, 4, and Figs. 9, 10, 11 are ordinarily of sufficient precision for such purposes.

2. Either months or latitudes (with assumption of constant longitude or longitude zone) may be shown as scale parameters.

(a) For purposes of general use over a variety of locations there is greater advantage in presenting latitude parameters.

(b) For use pertinent to a particular fixed location (i.e. a control point of a constantly-used transmission path, or the location of an ionosphere observing station) there is greater advantage in the presentation of months as parameters.

3. Constant, up-to-the minute revision is readily possible.

It is obvious that this type of diagram is quite as useful as a means of historic record as of prediction. Two observations made for identical location, season, and time of day, but for a differing sunspot number, establish a point on the central scale of the nomogram. Additional observations, as they are available, may be readily spotted as alterations in the location of points establishing these central scales. It suffices to plot thus only the values of f^o and 4000-km muf, in the nomogram types of Figs. 2, 3, 4 and Figs. 9, 10, 11 since these require no computations performed upon the data usually issued by ionosphere observing stations. The variations in X or M4000 will be apparent as a progressive shift with time in the loci of established points.

This effectively combines the processes of basic data correlation and prediction, so that, at any time, one of these nomograms, kept up to date with incoming data, presents the currently best available prediction chart. Reissuance of such charts, thus, would be contingent upon the degree of variation exhibited by newly added values, and upon the desired precision for practical use. With accumulation of correlated basic data, the relatively infrequent need of reissuance of these nomograms should effect considerable economy.

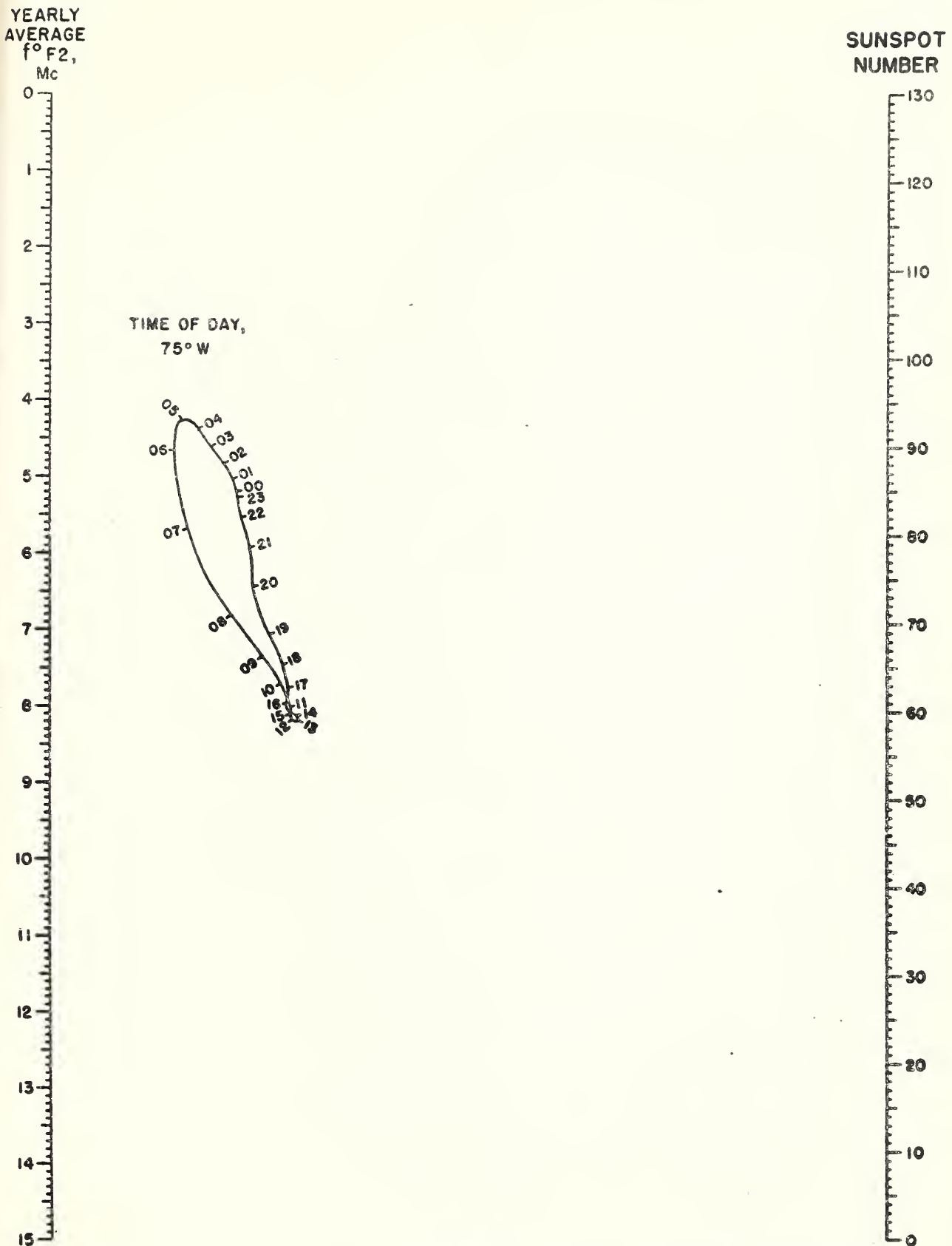


Fig. 1.

NOMOGRAM FOR OBTAINING YEARLY AVERAGE f^oF2 AT WASHINGTON, D. C.

MONTHLY
AVERAGE
 $f^{\circ}F_2$,
Mc



SUNSPOT
NUMBER



TIME OF DAY,
75° W

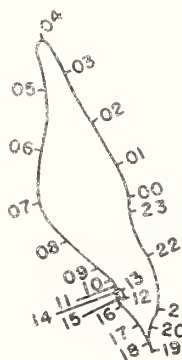


Fig. 2.

NOMOGRAM FOR OBTAINING MONTHLY AVERAGE $f^{\circ}F_2$, JUNE, AT WASHINGTON, D.C.

A vertical ruler scale from 0 to 15 cm. The scale is marked with major numbers from 0 to 15 and minor markings for millimeters. The 0 mark is at the top, and the 15 mark is at the bottom. The ruler is oriented vertically.

A vertical scale ranging from 0 to 130. Major tick marks are labeled at intervals of 10 (0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130). Minor tick marks are present between the major ones, representing increments of 1 unit.

NOMOGRAM FOR OBTAINING MONTHLY AVERAGE $f^{\circ}F_2$, SEPTEMBER, AT WASHINGTON, D.C.

MONTHLY
AVERAGE
 $f^{\circ}F_2$,
Mc

SUNSPOT
NUMBER



TIME OF DAY,
75° W

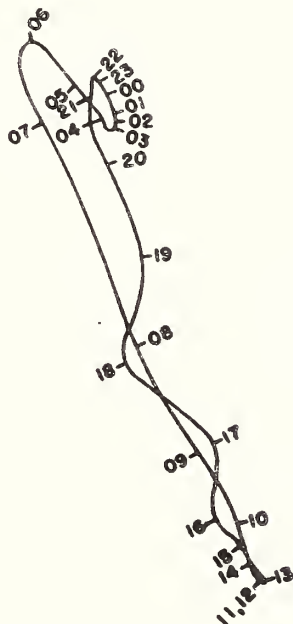


Fig. 4.

NOMOGRAM FOR OBTAINING MONTHLY AVERAGE $f^{\circ}F_2$, DECEMBER, AT WASHINGTON, D.C.

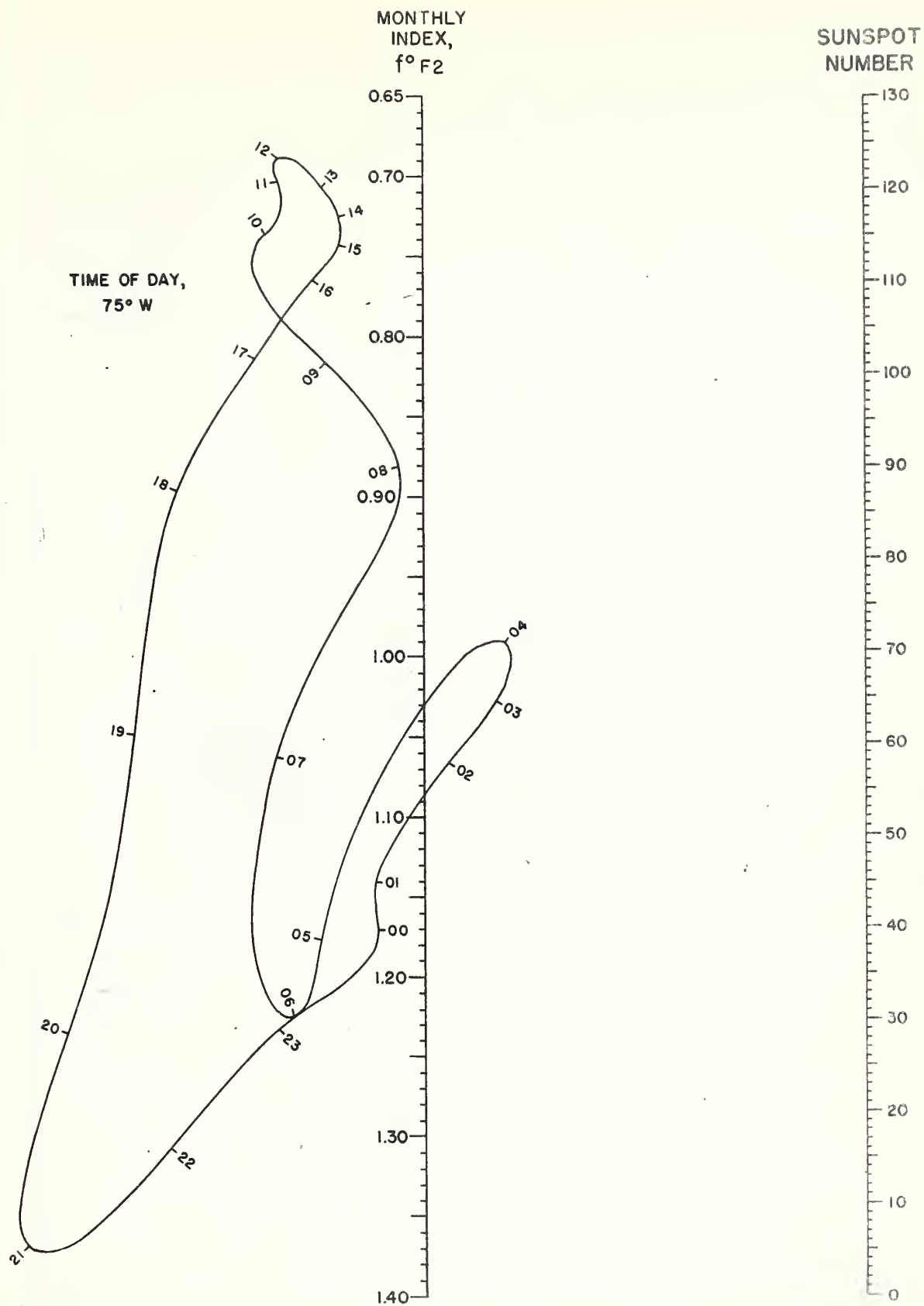


Fig. 5.
NOMOGRAM FOR OBTAINING JUNE MONTHLY INDEX FOR $f^{\circ}F_2$ AT WASHINGTON, D.C.

MONTHLY
INDEX,
 $f^{\circ}F_2$

SUNSPOT
NUMBER

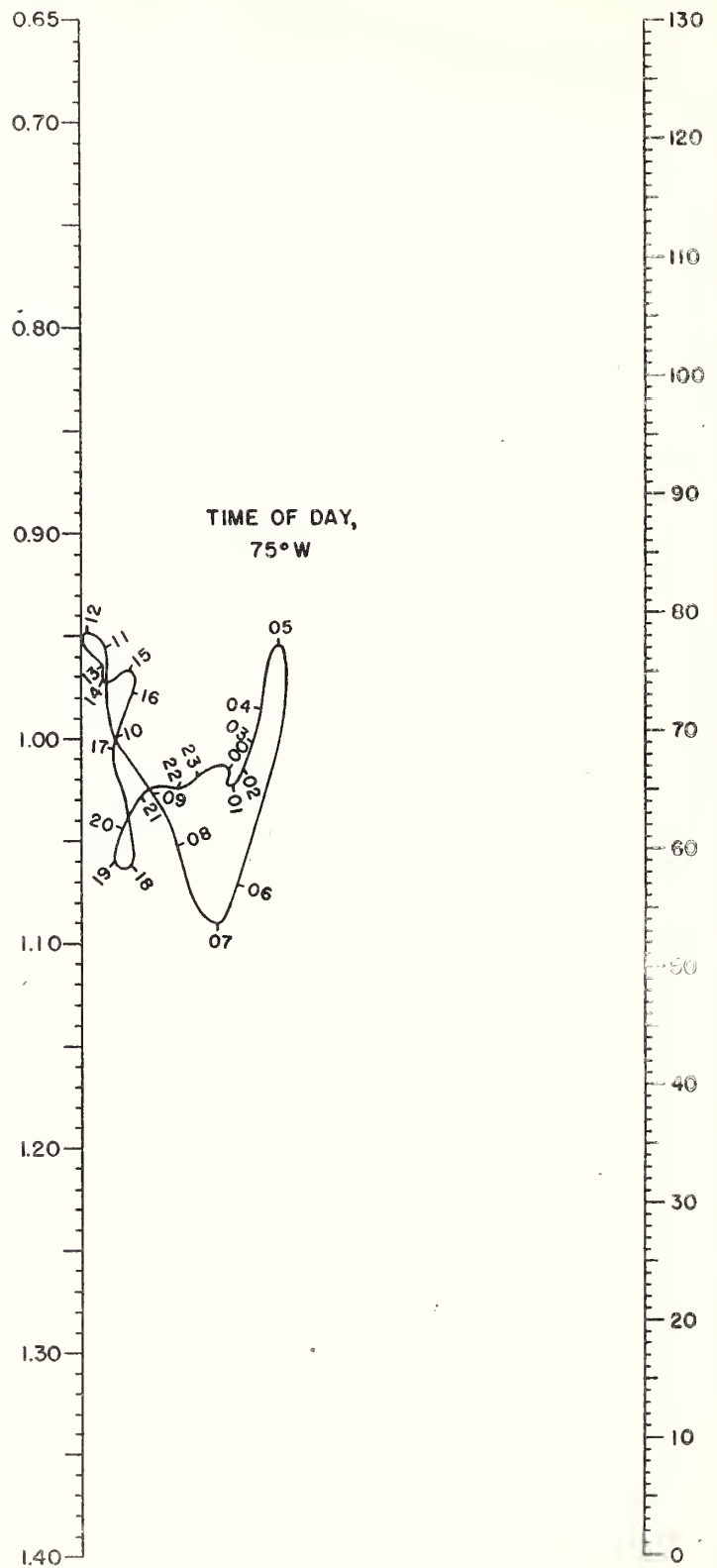


Fig. 6.

NOMOGRAM FOR OBTAINING SEPTEMBER MONTHLY INDEX FOR $f^{\circ}F_2$ AT WASHINGTON, D.C.

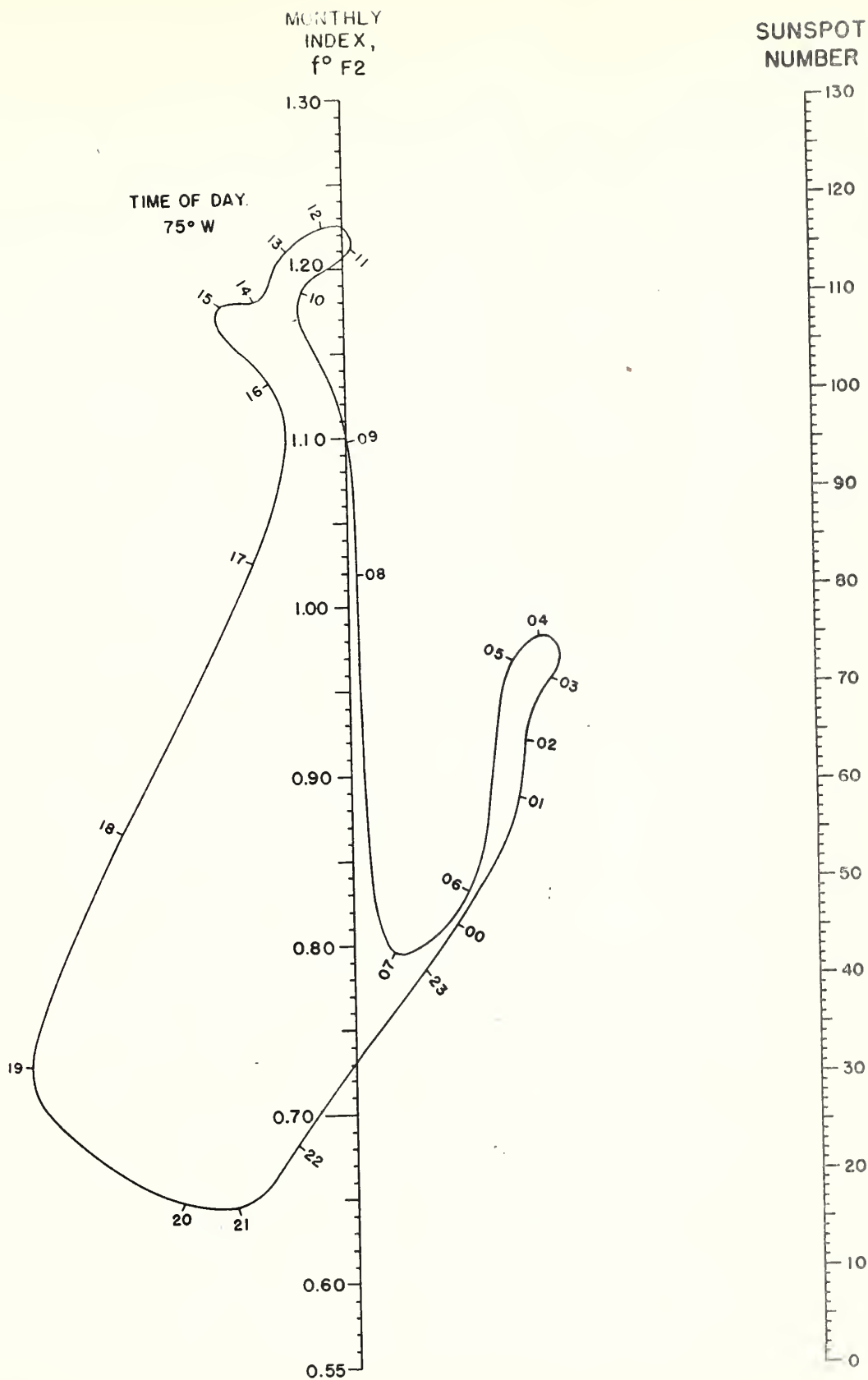


Fig. 7.

NOMOGRAM FOR OBTAINING DECEMBER MONTHLY INDEX FOR $f^{\circ}F_2$ AT WASHINGTON, D.C.

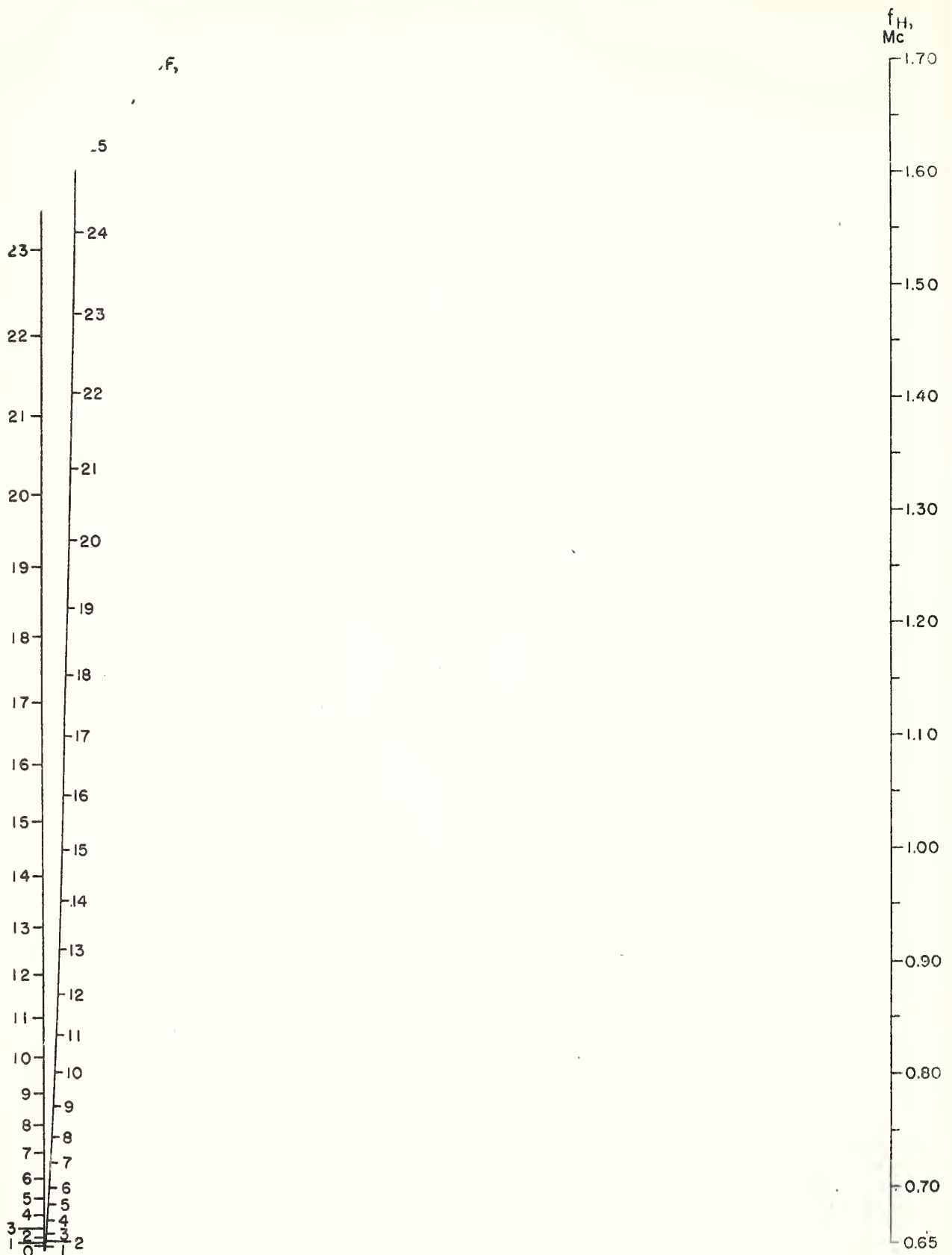


Fig. 8.
NOMOGRAM FOR OBTAINING ZERO-MUF, OR f_x^X , FROM f_o AND f_H .

MONTHLY
AVERAGE
F2 4000-MUF,
Mc

SUNSPOT
NUMBER

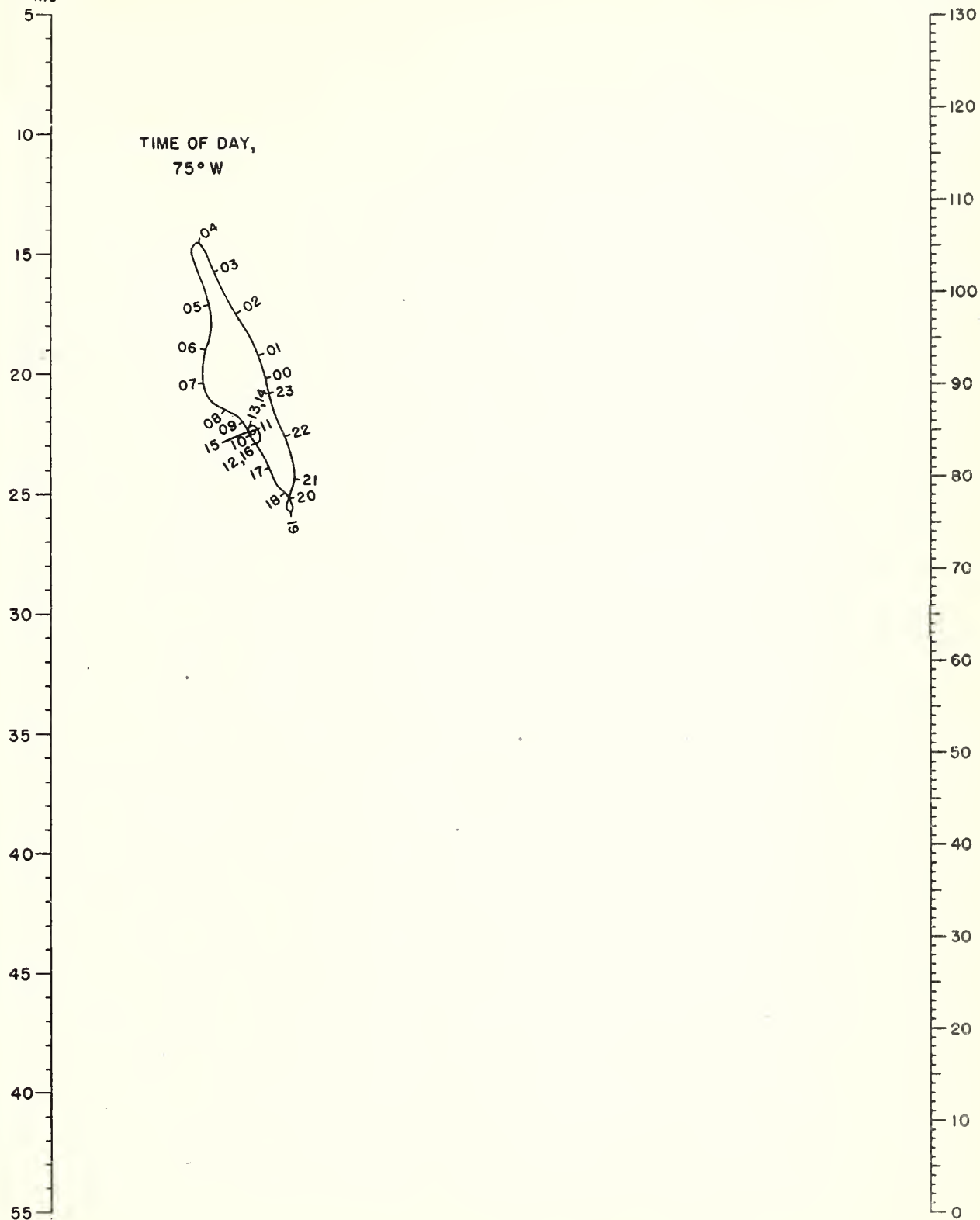


Fig. 9.

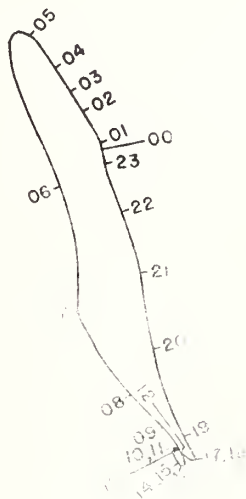
NOMOGRAM FOR OBTAINING MONTHLY AVERAGE F2 4000-MUF, JUNE, AT WASHINGTON, D. C.

MONTHLY
AVERAGE
F2 4000-MUF,
Mc

SUNSPOT
NUMBER

5
10
15
20
25
30
35
40
45
50
55

TIME OF DAY,
75°W



130
120
110
100
90
80
70
60
50
40
30
20
10
0

Fig. 10.

NOMOGRAM FOR OBTAINING MONTHLY AVERAGE F2 4000-MUF, SEPTEMBER, AT WASHINGTON, D. C.

MONTHLY
AVERAGE
F2 4000 MUF,
Mc

SUNSPOT
NUMBER

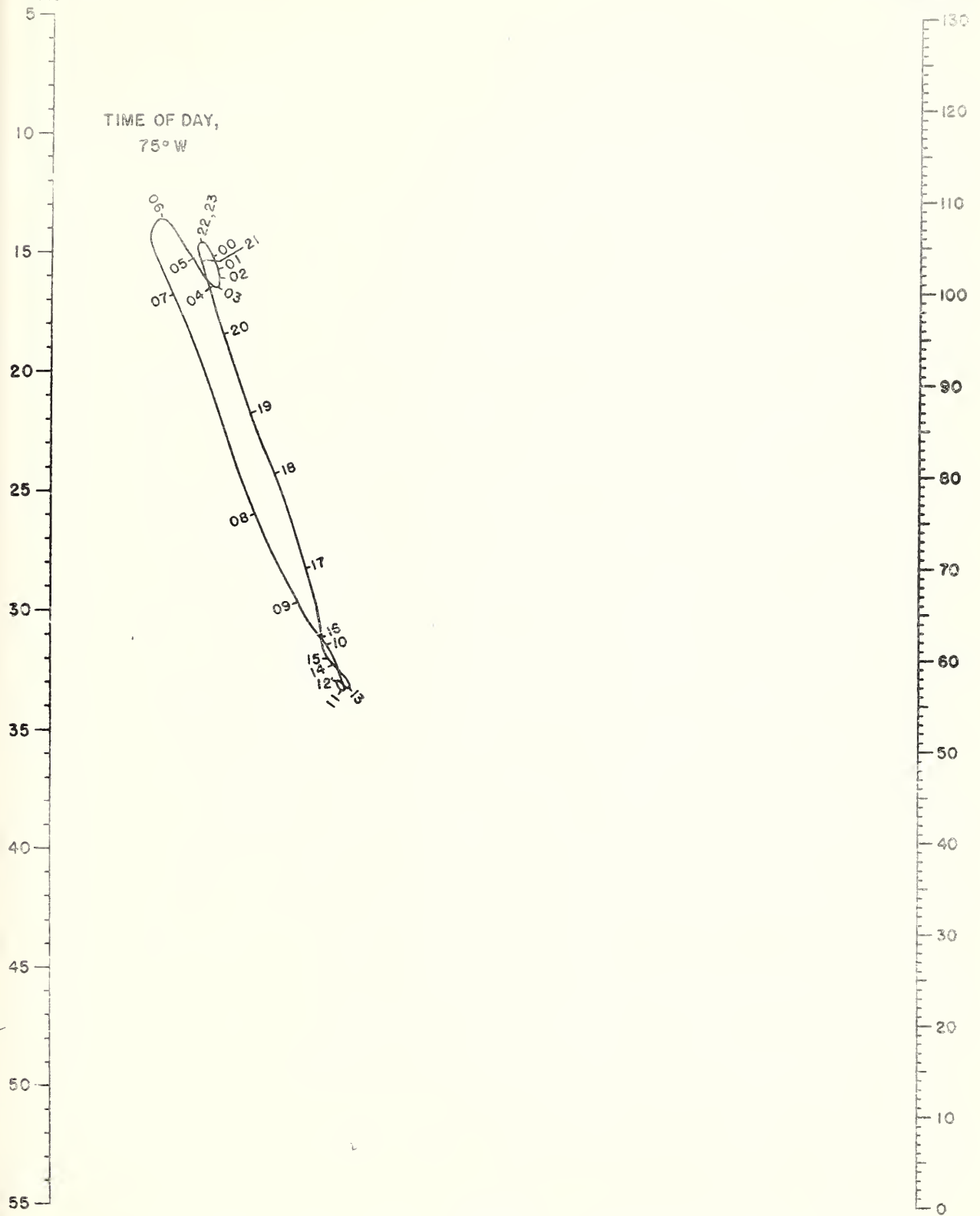


Fig.11.

NOMOGRAM FOR OBTAINING MONTHLY AVERAGE F2 4000-MUF, DECEMBER, AT WASHINGTON, D.C.

MONTHLY
AVERAGE
F2-M4000

SUNSPOT
NUMBER

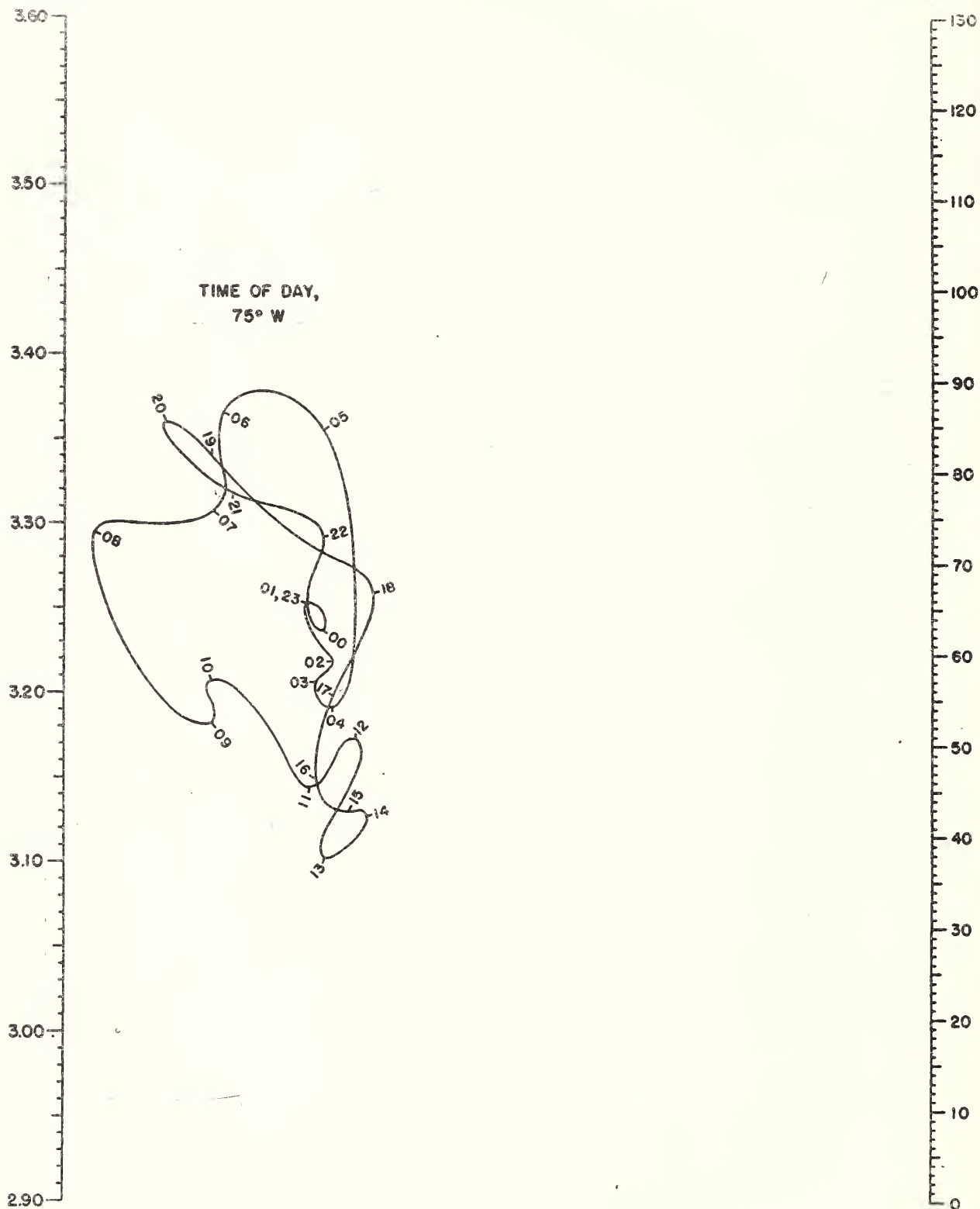


Fig. 12.

NOMOGRAM FOR OBTAINING MONTHLY AVERAGE F2-M4000, JUNE, AT WASHINGTON, D.C.

MONTHLY
AVERAGE
F2-M4000

SUNSPOT
NUMBER

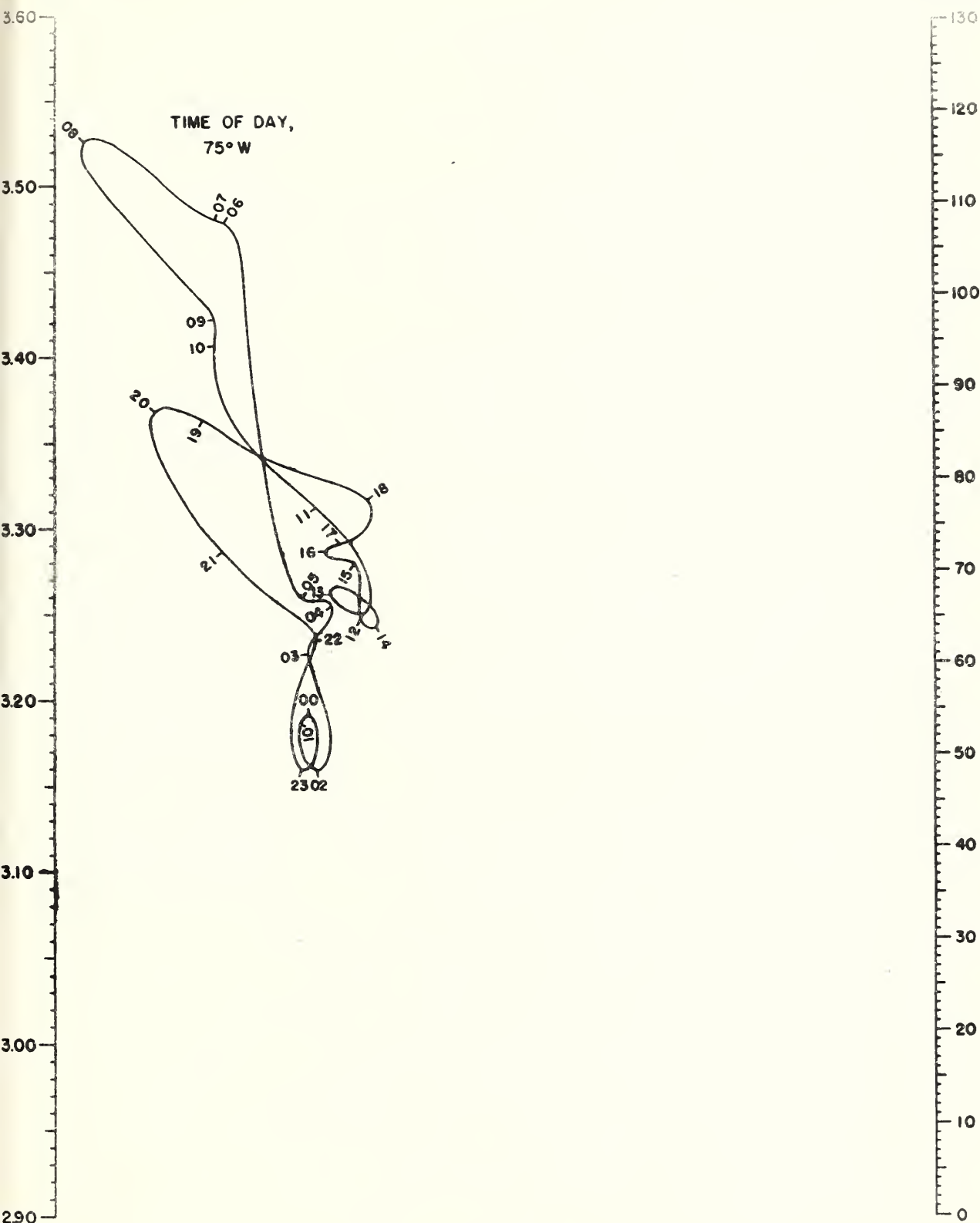


Fig. 13.

NOMOGRAM FOR OBTAINING MONTHLY AVERAGE F2-M4000, SEPTEMBER, AT WASHINGTON, D.C.

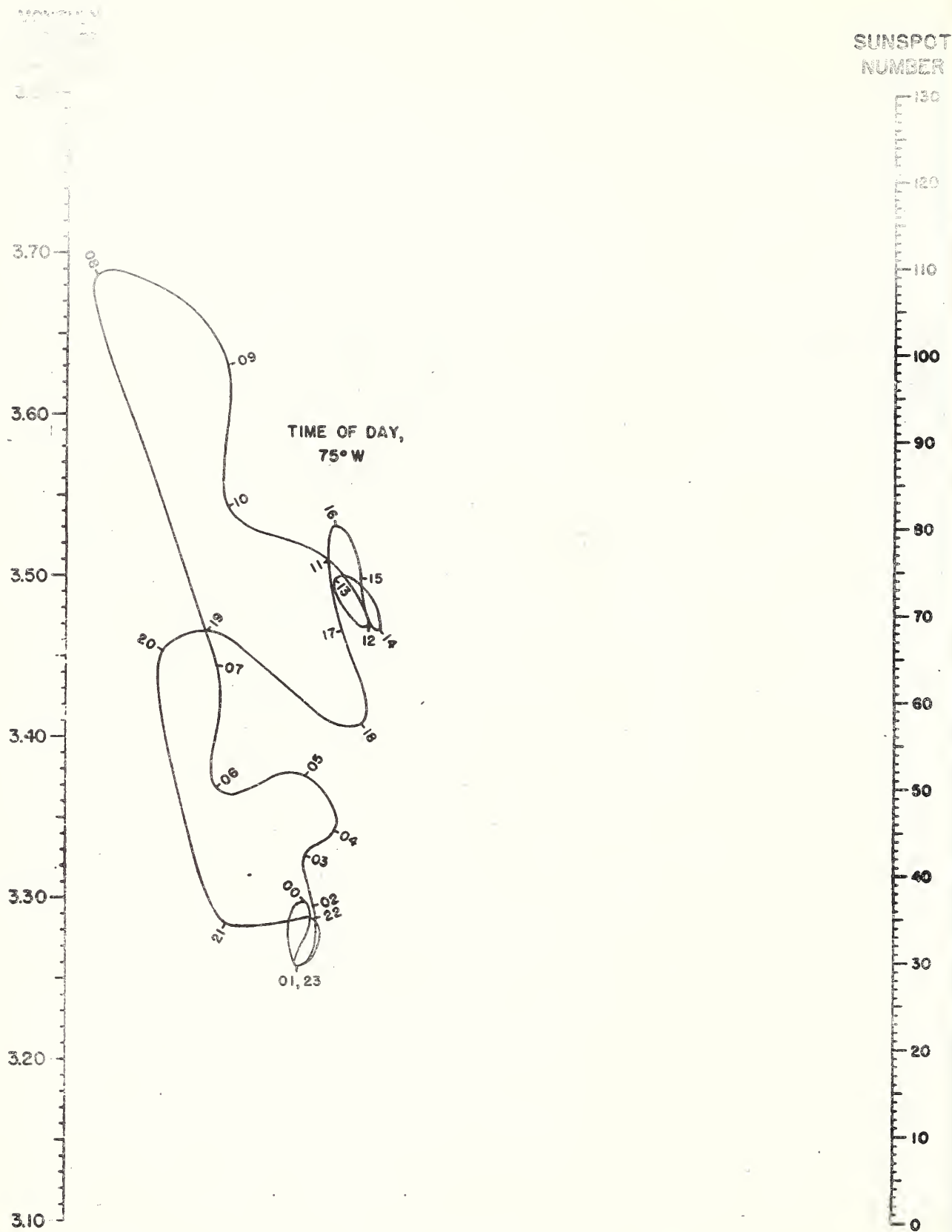


Fig. 14.

NOMOGRAM FOR OBTAINING MONTHLY AVERAGE F2-M4000, DECEMBER, AT WASHINGTON, D.C.